Energy Dependent Fission Product Yields

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Lawrence Livermore National Laboratory

Workshop for Applied Nuclear Data Activities (WANDA)

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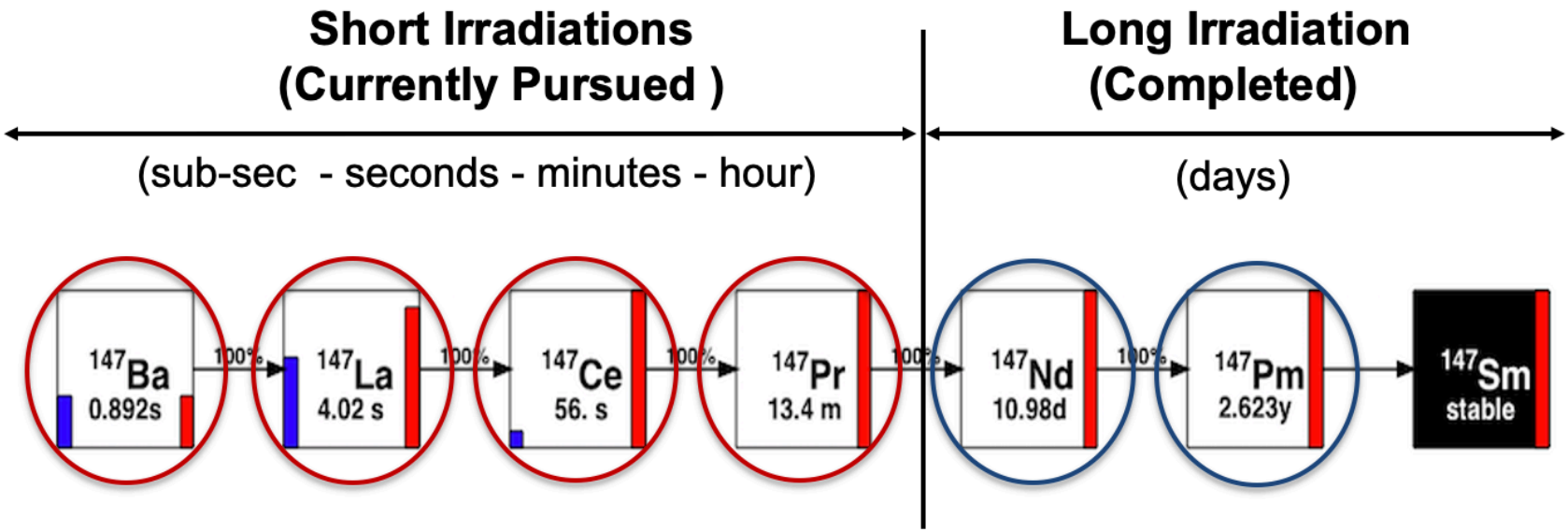
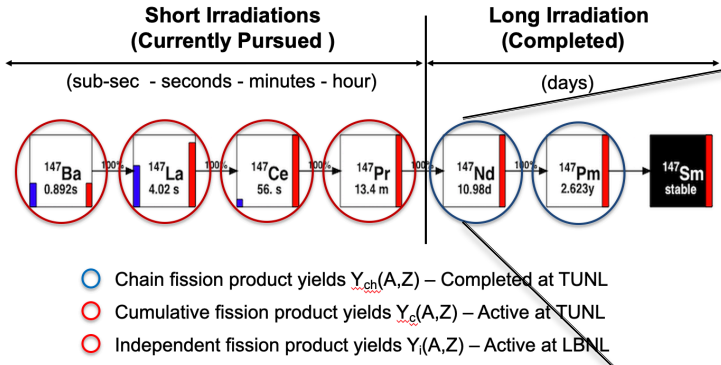
Motivation: Provide High-precision, Self-consistent FPY Data to Support Fission Theory and Evaluation



- Chain fission product yields $Y_{ch}(A,Z)$ – Completed at TUNL
- Cumulative fission product yields $Y_c(A,Z)$ – Active at TUNL
- Independent fission product yields $Y_i(A,Z)$ – Active at LBNL

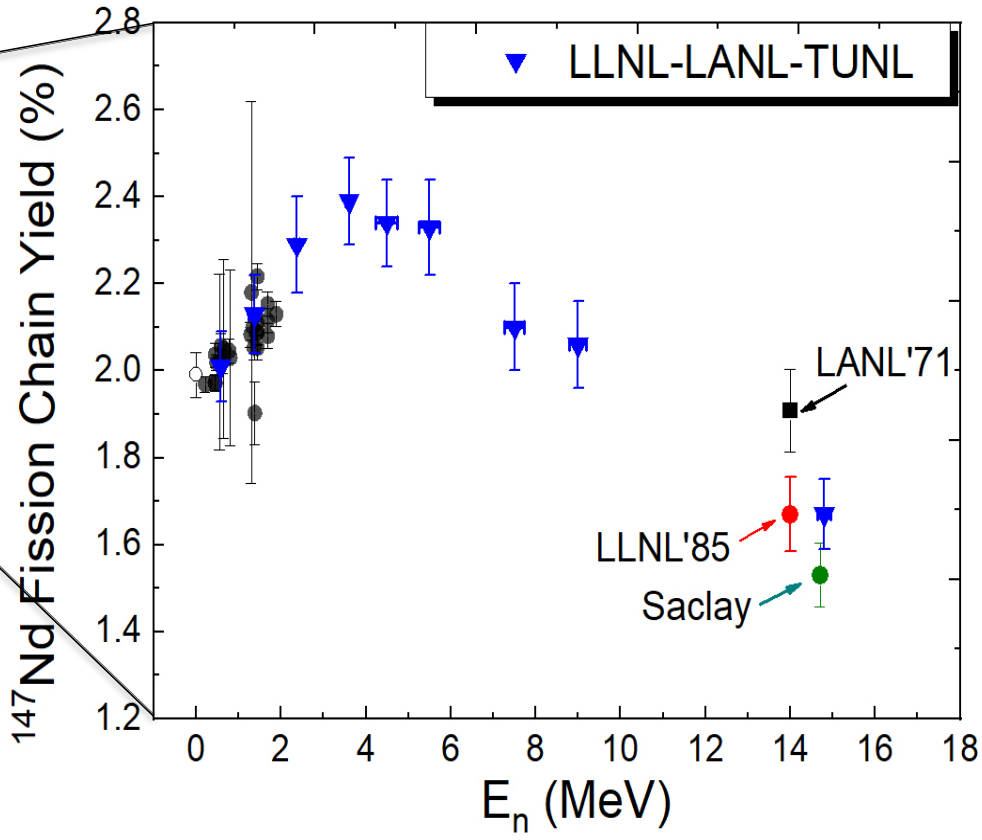
Goal: Predicting independent and cumulative FPYs data simultaneously and consistently in the energy-dependent manner

Previous Campaign: Cumulative FPYs from Long Irradiation



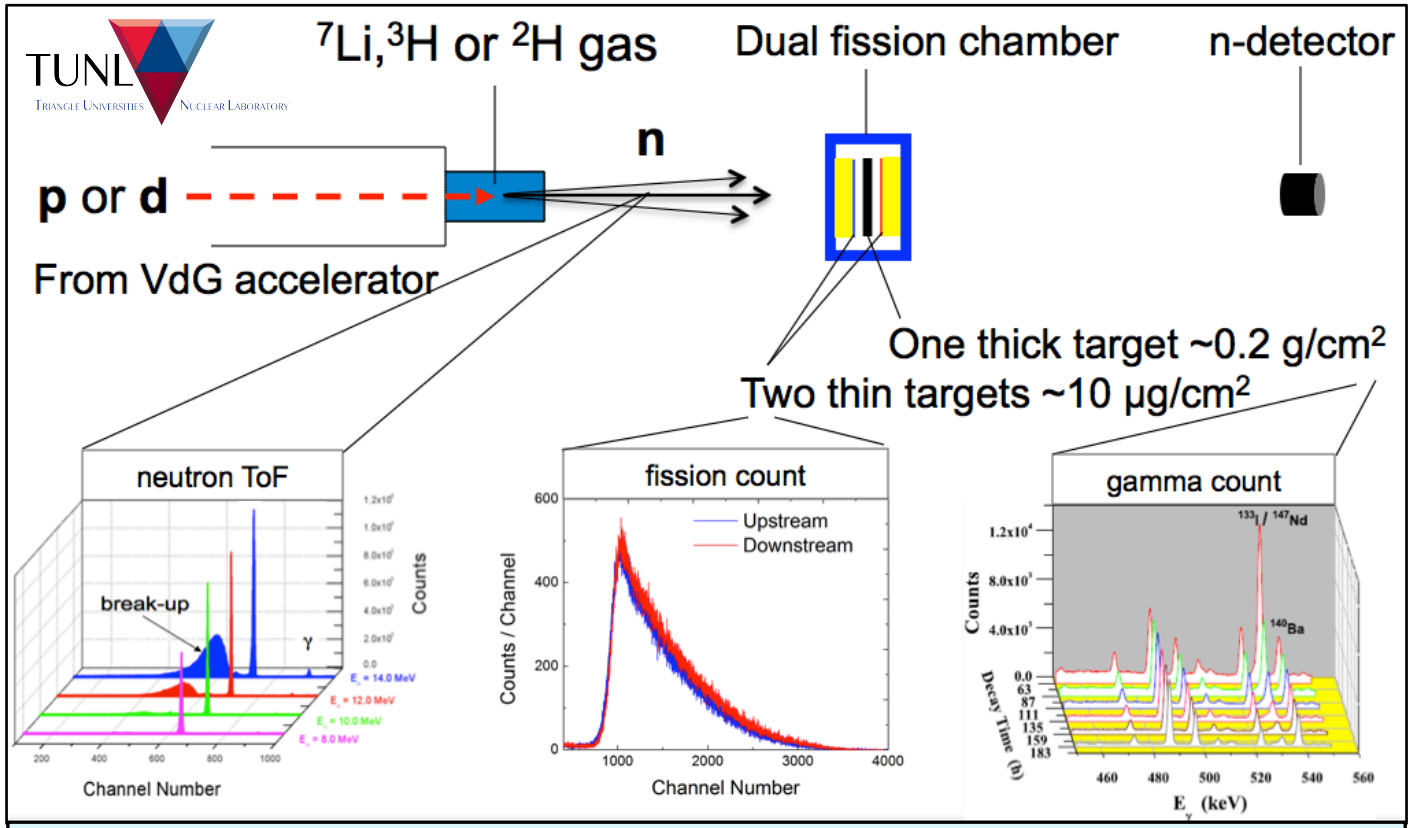
- Peculiar energy dependency
- There is a positive slope of the ^{147}Nd FPY from 0.5 to ~4.0 MeV:

  $\Delta Y(^{147}Nd)/\Delta E_n = (5.8\pm1.5)\%/MeV$
- At higher energies the FPY for ^{147}Nd turns over and decreases



NIM A **757,** 7 (2014); Nucl. Data Sheets **119**, 121 (2014); Nucl. Data Sheets **119**, 324 (2014), J. Rad. Nucl. Chem 10.1007 (2015); PRC **91**, 064604 (2015); PRC **93**, 014611 (2016); Nucl. Data Sheets **131**, 319 (2016), PRC **95**, 024608 (2017); NIMA **854**, 40 (2017); Four Conference Proceeding (2016, 2017, 2018, 2019), M. Gooden et al. Manuscript in preparation.

Fission Product Yield Measurements at TUNL using Monoenergetic Neutron Beams

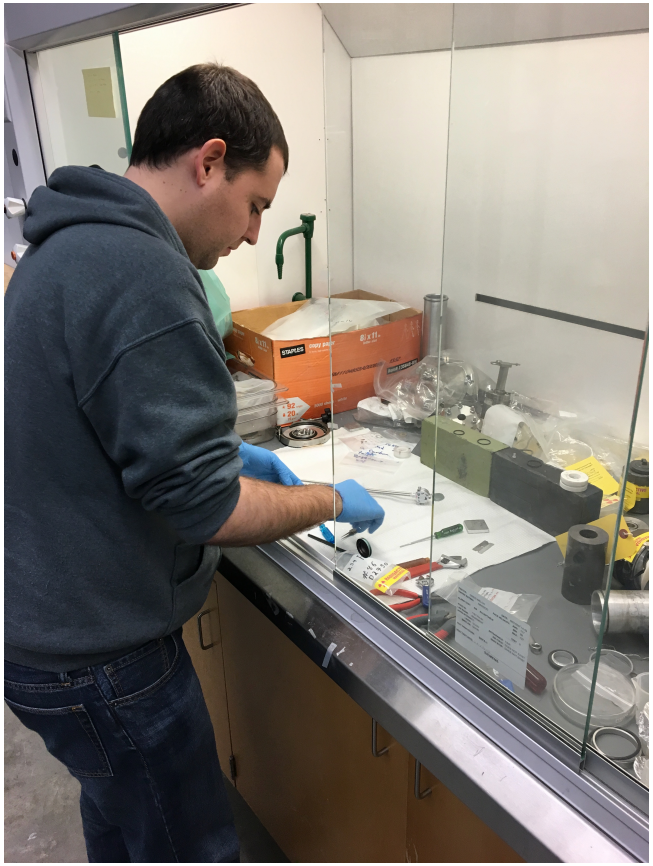


$$FPY = (Gamma\_count) / Fission\_count) * (m_{thin} / m_{thick}) * C_i$$

NIM A **757,** 7 (2014); Nucl. Data Sheets **119**, 121 (2014); Nucl. Data Sheets **119**, 324 (2014), J. Rad. Nucl. Chem 10.1007 (2015); PRC **91**, 064604 (2015); PRC **93**, 014611 (2016); Nucl. Data Sheets **131**, 319 (2016), PRC **95**, 024608 (2017); NIMA **854**, 40 (2017); Four Conference Proceeding (2016, 2017, 2018, 2019)

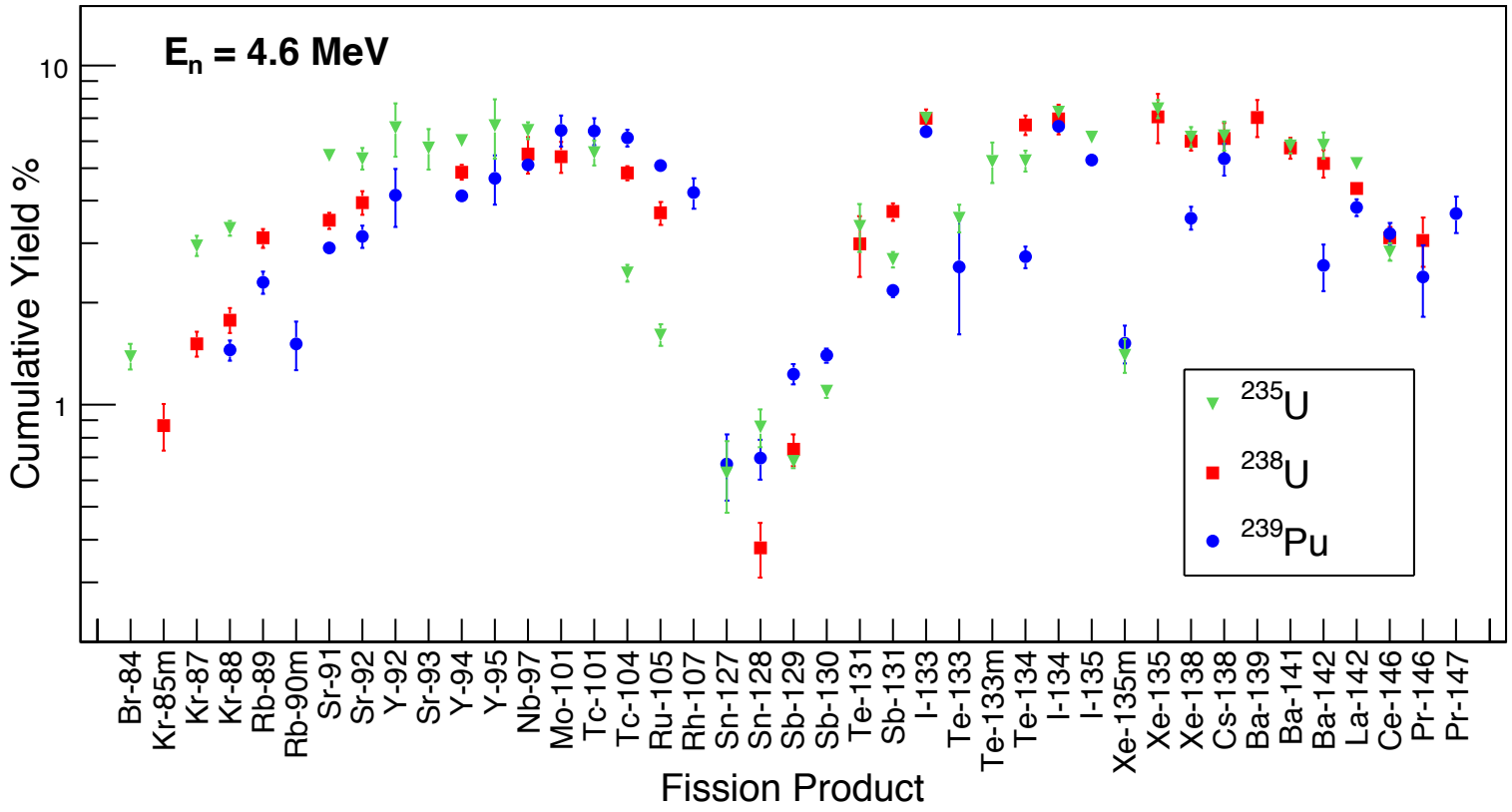
Short-lived Fission Product Yields (min – hours)

- Six irradiations on ^{235}U, ^{238}U, and ^{239}Pu at E_n = 0.56, 1.5, 4.6, 6.5, 9.0, and 14.8 MeV
  - Irradiation time = 1 h
  - Transfer time ~ 4 minutes using the JACK-RABBIT System
  - Counting time = one week of continuous counting
- FPY data for more than 45 fission products with half-live of few minutes to a few days
- Providing time dependent FPY information to the FIER* code



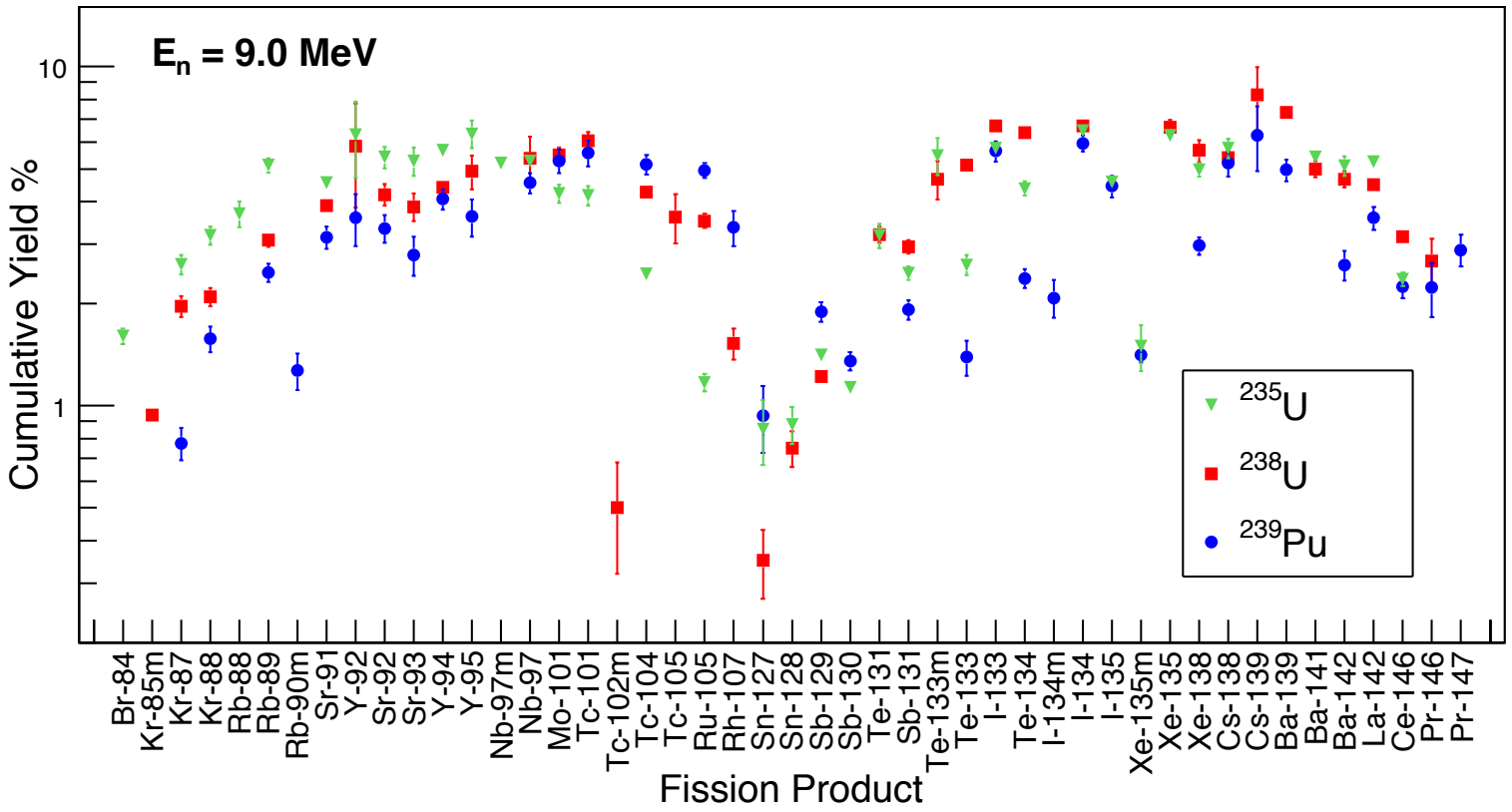
* E. Matthews *et al*. FIER code. NIMA A 891 (2018) 111–117

Short-lived FPYs from Neutron Induced Fission of ^{235}U, ^{238}U, and ^{239}Pu at E_n= 4.6 MeV



J. Silano et al. Prepared for publication

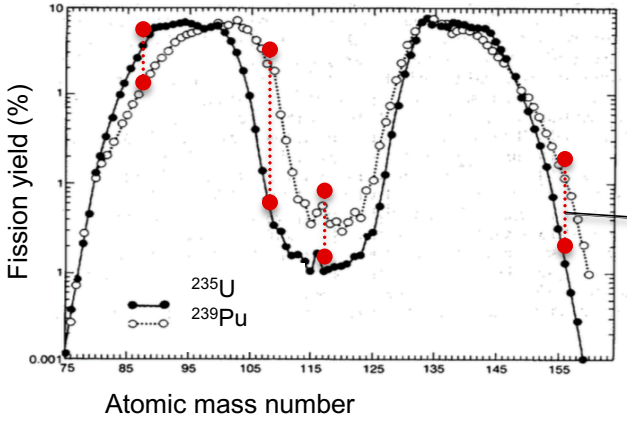
Short-lived FPYs from Neutron Induced Fission of ^{235}U, ^{238}U, and ^{239}Pu at E_n= 9.0 MeV



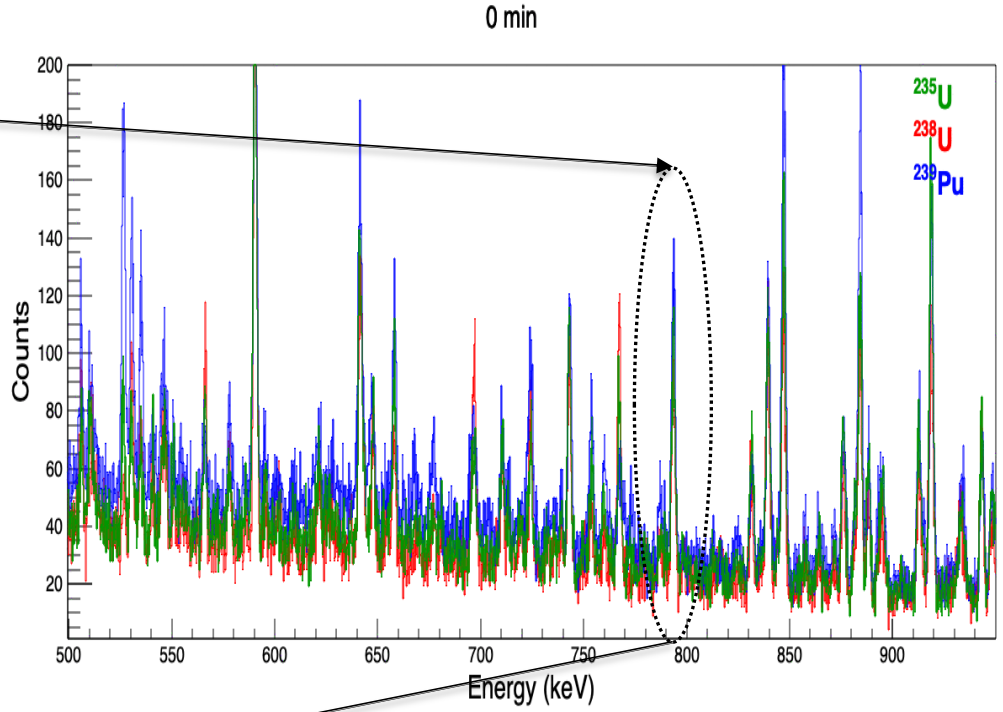
J. Silano et al. Prepared for publication

Fission Gamma-Ray History of the FPY data

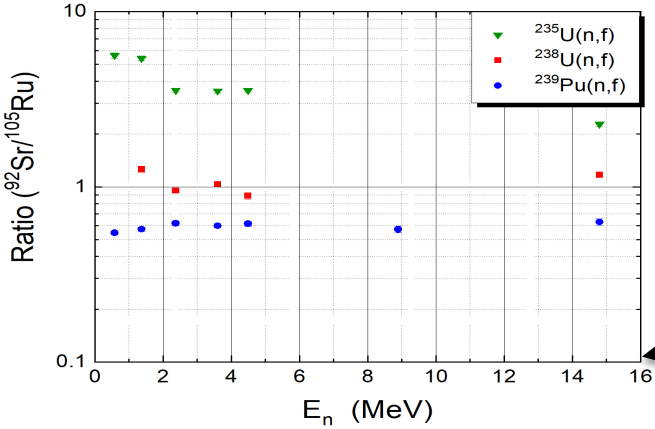
Cumulative fission product yields of ^{235}U and ^{239}Pu as a function of product mass



Time evolution of fission product yield γ-rays from ^{235}U, ^{238}U and ^{239}Pu



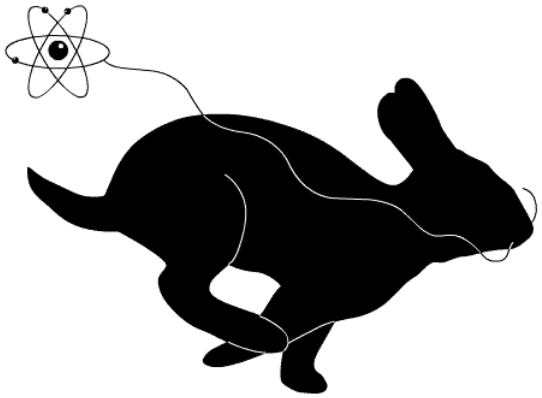
Fission product gamma-ray ratio as function of incident neutron energy



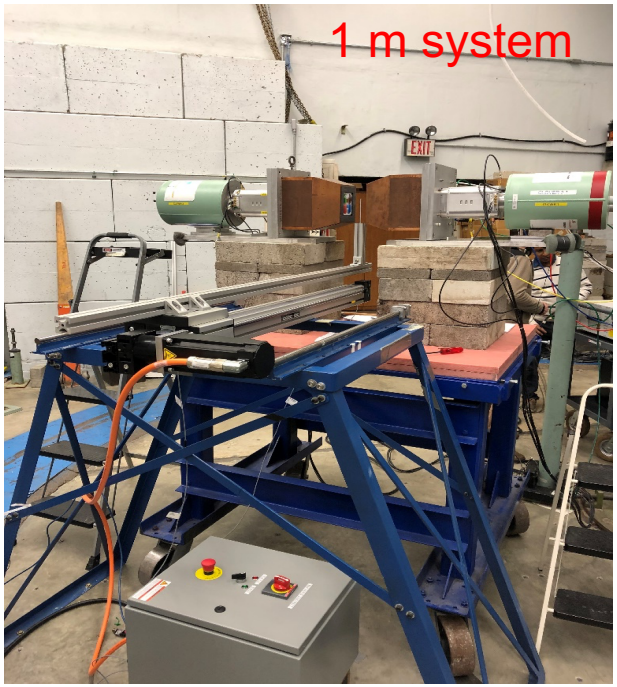
A. Tonchev et al. LLNL report. Prepared for publication

Fastest Sample-Irradiated Transfer System in the Entire NNSA Complex

RApid
Belt-driven
Irradiated
Target
Transfer
System



RABITTS



Completed

- 1 and 10 m transfer systems
- Transfer time = 400ms/1m or 1s/10m
- Fully synchronized with the DAQ system and beam time structure
- User defined cycles (t_{irr}, t_{dec}, t_{mes}) can be repeated many times
- List-mode DAQ based on digital electronics

Performed

- Significant background improvement
- Multiple cycles on ^{235}U, ^{238}U, and ^{239}Pu at E_n= 1.5, 2.0, and 4.6 MeV

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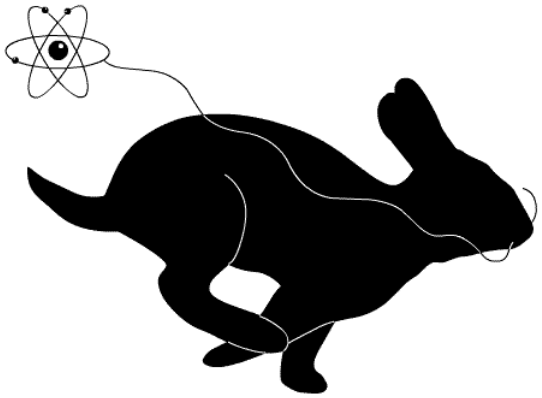

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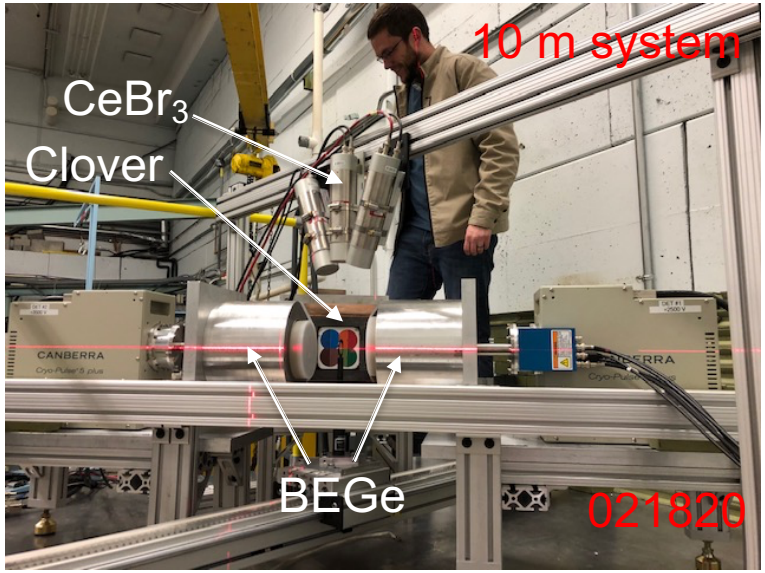


Completed

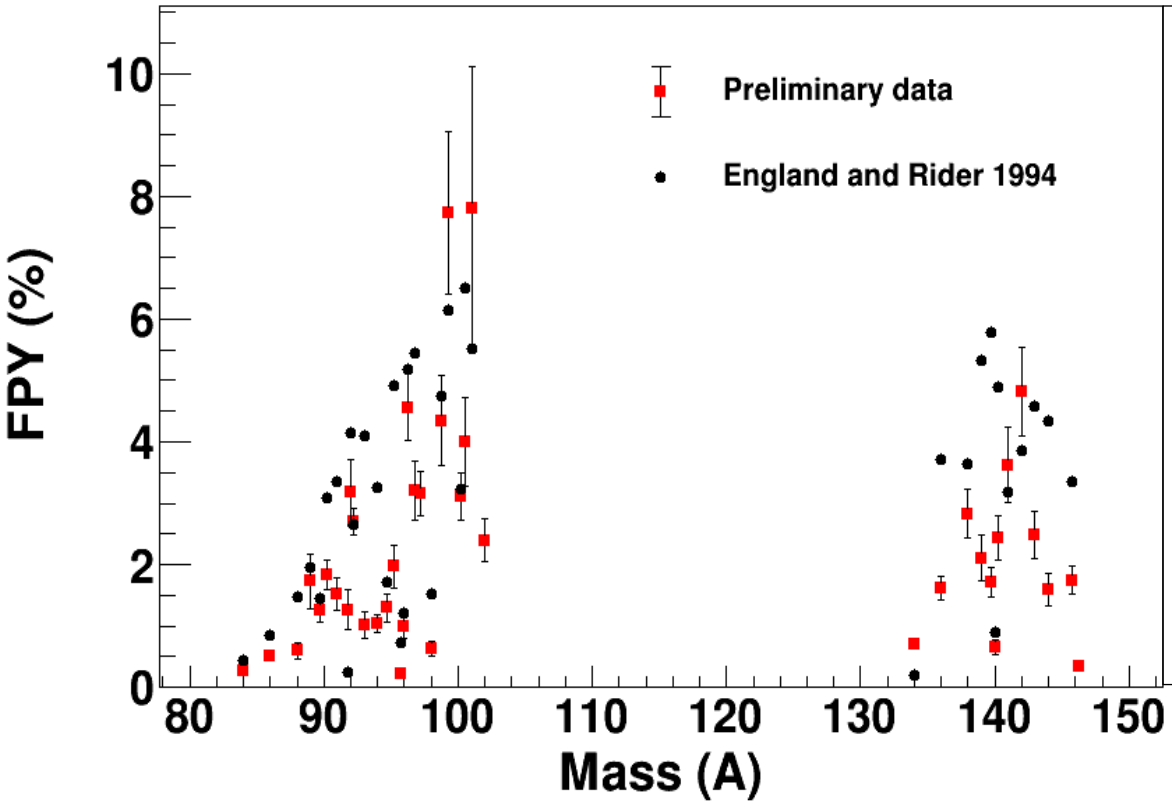
- Complete redesign of the 10 m system
- Obtained state-of-the-art BEGe detectors, combined with digitized based DAQ. Significant (>30%) energy resolution of the fission gamma-ray spectra

Performed

- FPY data for FPs with half-live of sub-second to a few minutes
- Developed analytical methods to process complex gamma-ray spectra

RABBITS in Action

Preliminary ^{238}U FPY Data at E_n = 2.0 MeV



Measured FPYs

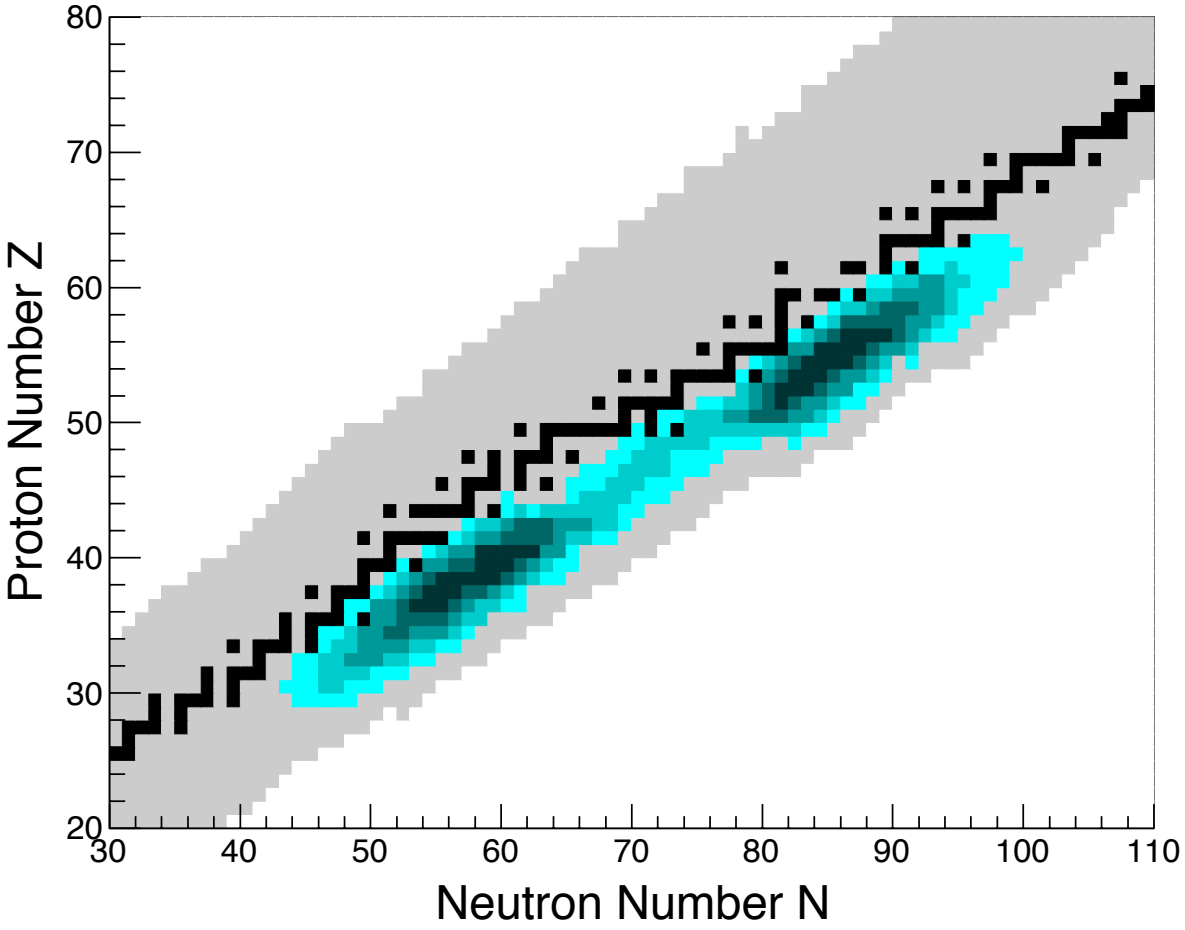
- Observed over 300 γ-rays resulting from fission, representing over 87 fission products
- Preliminary FPY values for 39 fission products

Additional data

- ^{235}U, ^{238}U, ^{239}Pu
- E_n = 2.0, 4.5 MeV

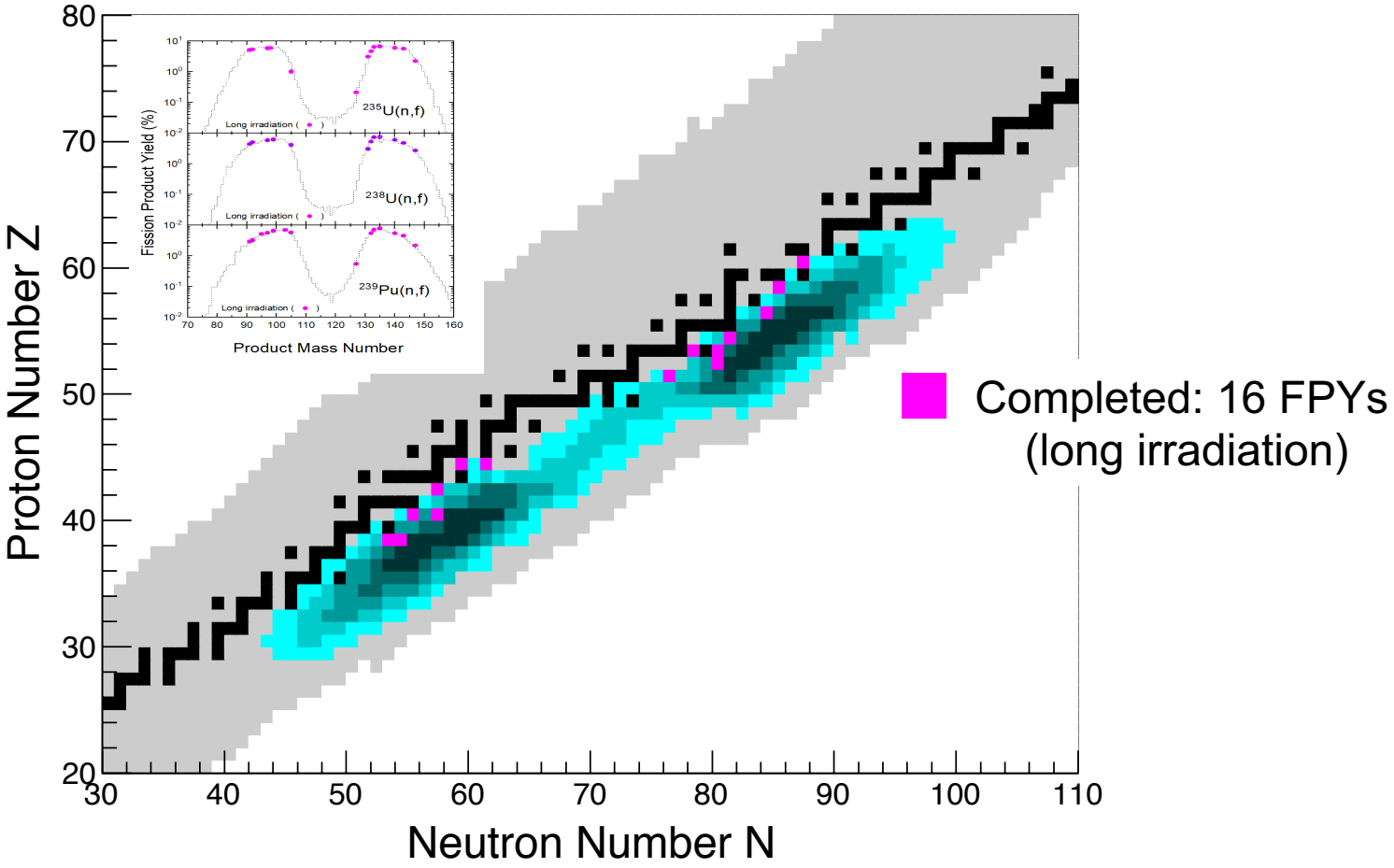
Constraining cumulative yields and moving towards independent yields

Fission Fragment Distribution*

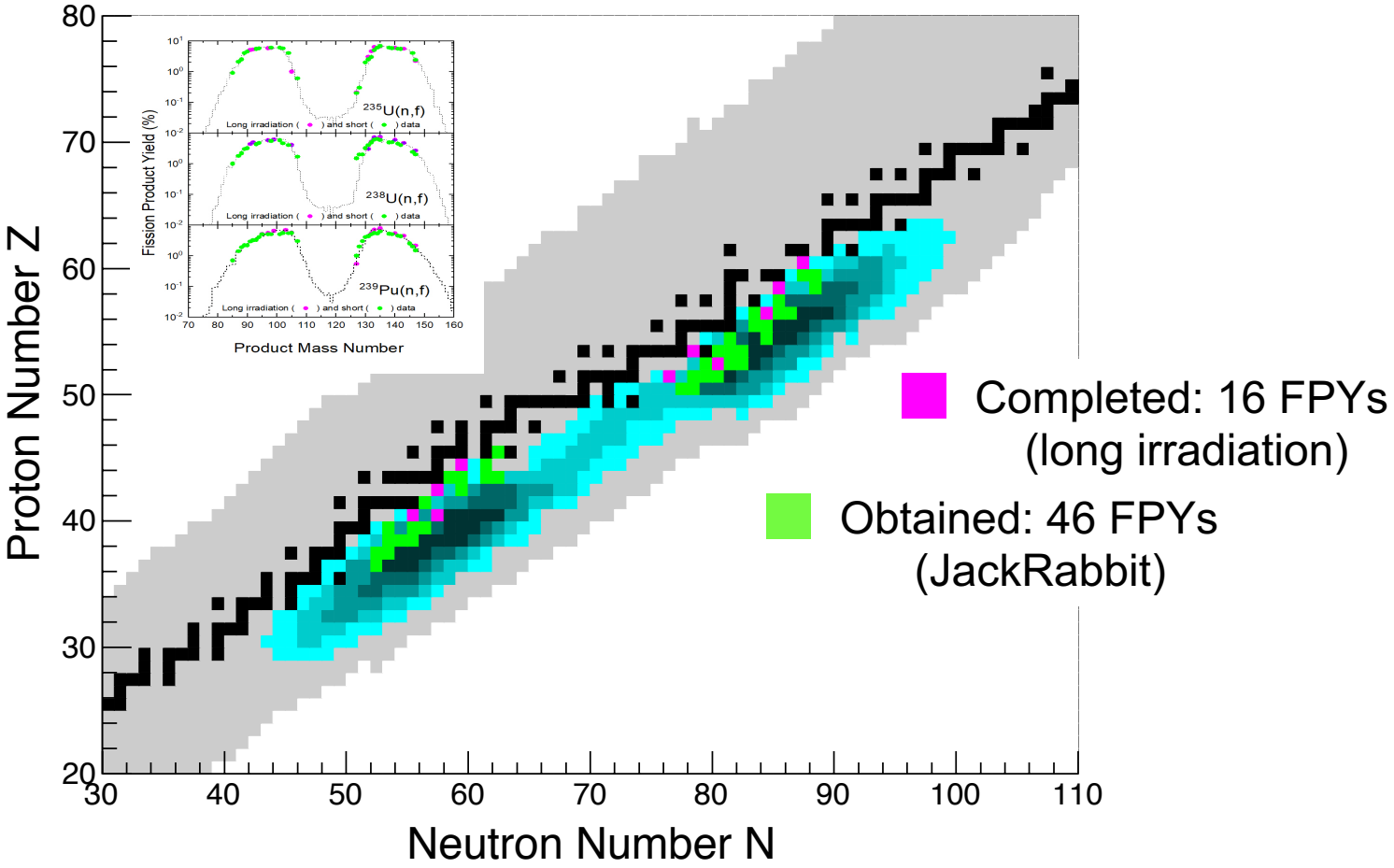


* T.R. England and B.F. Rider LA-SUB-94-170

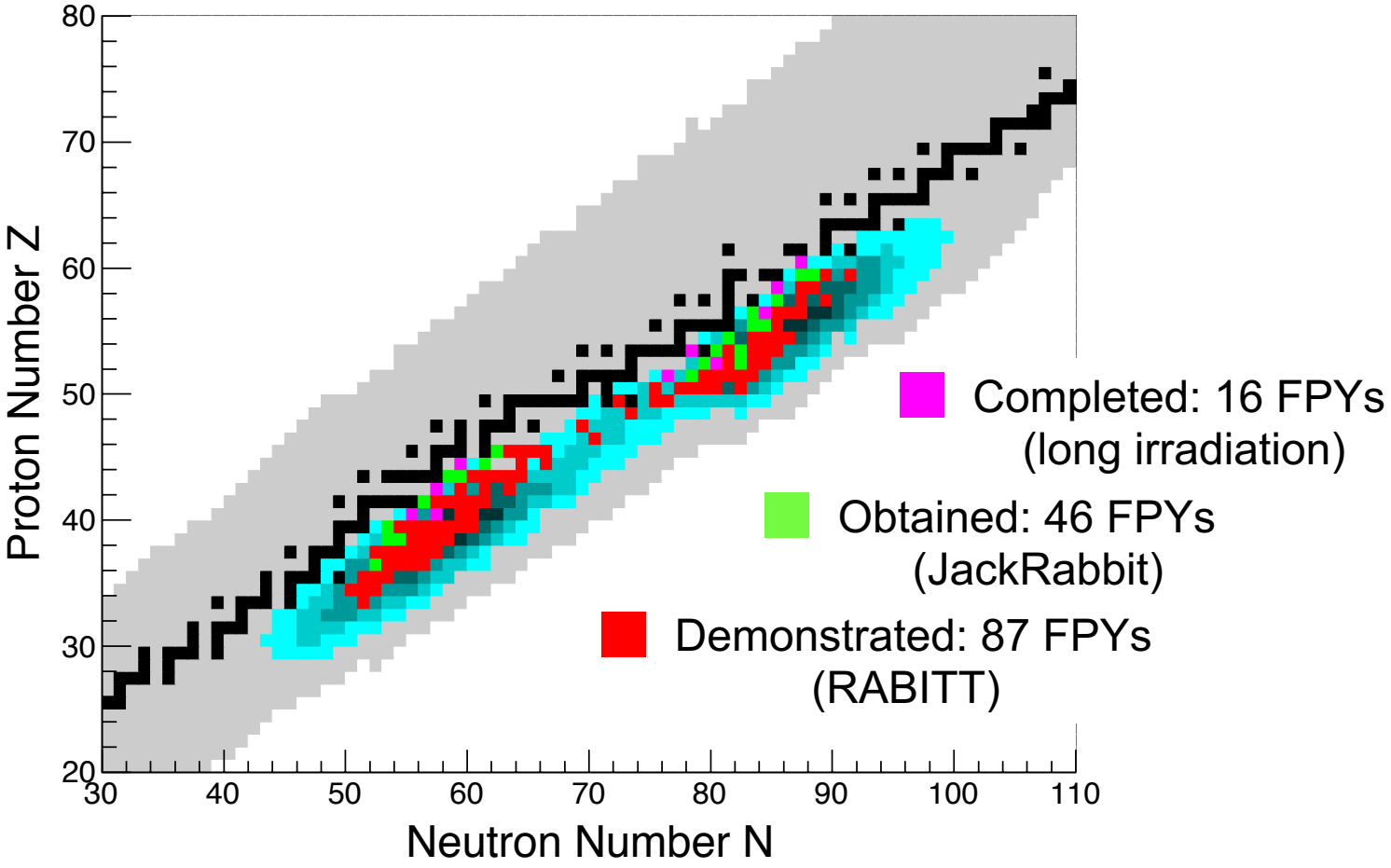
Fission Product Distribution



Fission Product Distribution



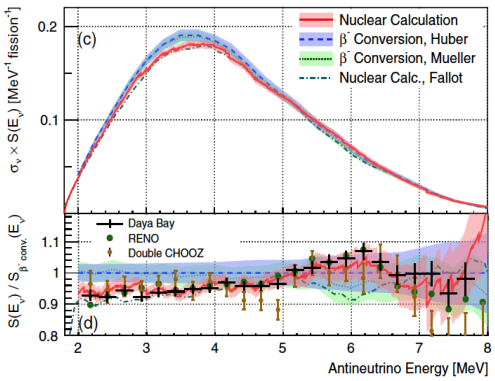
Fission Product Distribution

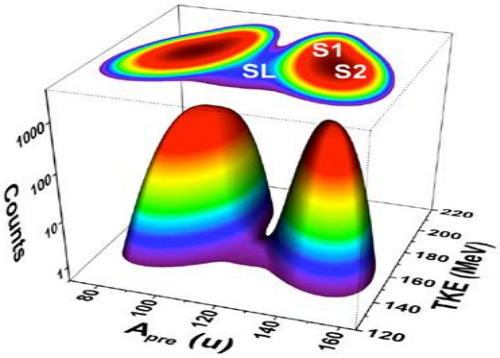


Broader Impact of the New Fission Product Yield Data

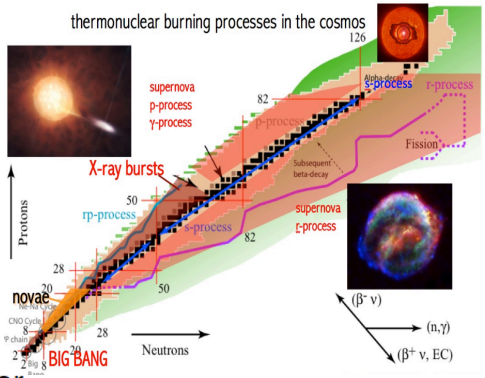
Basic Physics

Application





New FPY data base



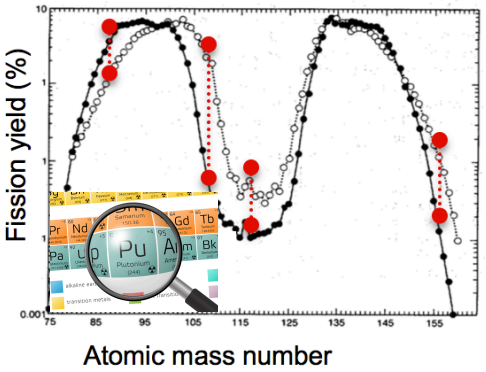
Reactor neutrino study

Nuclear astrophysics and cosmochemistry

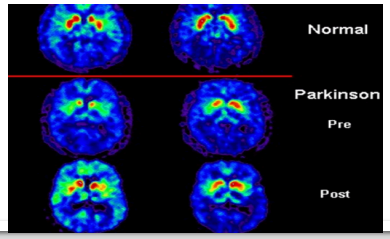
Fission Product Yields

Nuclear Forensics

Nuclear energy



Radio-isotope production for medical applications



Summary

- Constructed two (1 and 10 m) fast sample-transfer systems fully synchronized with the TUNL beam structure and DAQ
- Demonstrated unambiguous isotope identification (>87 fragments) using different cycle modes
- Consistent time-dependent FPY information from different symmetric and asymmetric modes of irradiation and counting

Short-lived fission products are in our reach!

Acknowledgements

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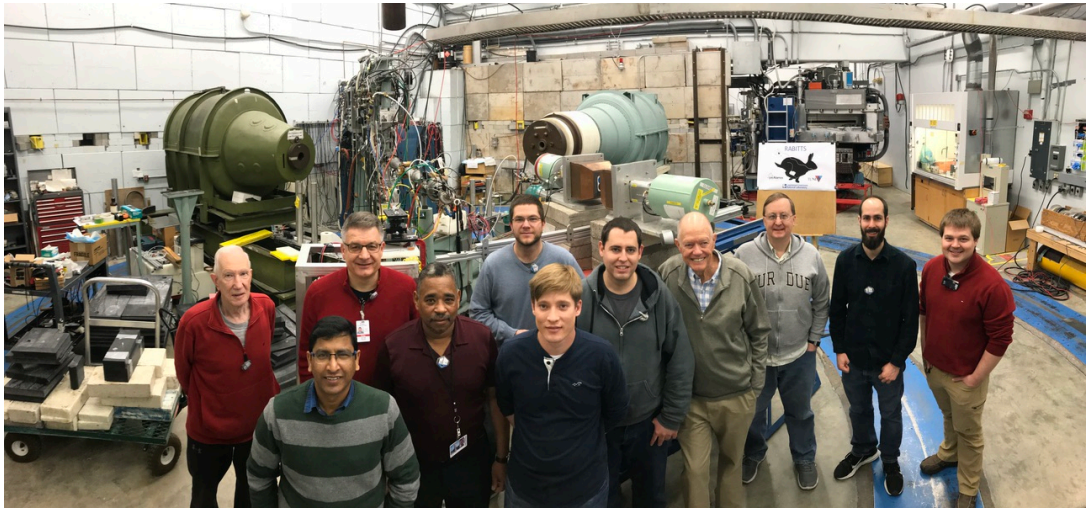

Strong Partnerships with the TUNL/LBNL Stockpile Stewardship Academic Alliance Group